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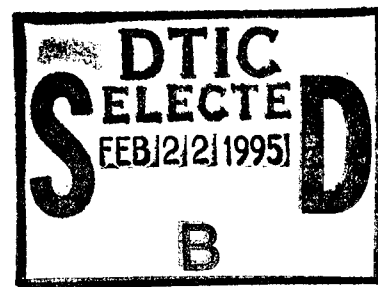
An Assessment of Support Items Directly Affecting the Success of US Space Launch Systems

July 31, 1994

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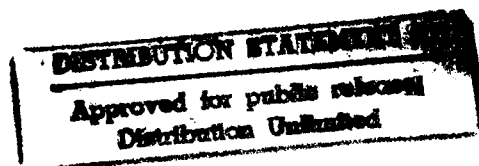1755 Jefferson Davis Hwy, Suite 802
Arlington, VA 22202

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1995 0210 058

REPORT DOCUMENTATION PAGE

Public reporting burden for this collection of information is estimated to average 1 hour per response, including the time for reviewing instructions, searching existing data sources, gathering and maintaining the data needed, and completing and reviewing the collection of information. Send comments regarding this burden estimate or any other aspect of this collection of information, including suggestions for reducing this burden, to Washington Headquarters Services, Directorate for Information Operations and Reports, 1215 Jefferson Davis Highway, Suite 1204, Arlington, VA 22202-4302, and to the Office of Management and Budget, Paperwork Reduction Project (0704-0188), Washington, DC 20503.

1. AGENCY USE ONLY (Leave blank)	2. REPORT DATE	3. REPORT TYPE AND DATES COVERED
	31 July 1994	Final Report

4. TITLE AND SUBTITLE

Support Reliability Metrics for Launch Systems: Assessment of Support Items Directly Affecting the Success of US Space Launch Systems

5. FUNDING NUMBERS

SDIO84-90-C-0002

6. AUTHOR(S)

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7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)

Dynamics Research Corporation
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Arlington, VA 22202

8. PERFORMING ORGANIZATION REPORT NUMBER

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)

Ballistic Missile Defense Organization
The Pentagon, BMDO/POI
Washington, DC 20305-71000

10. SPONSORING/MONITORING AGENCY REPORT NUMBER

11. SUPPLEMENTARY NOTES

Prepared for: US Air Force Space and Missile Systems Center, Los Angeles Air Force Base, CA 90009

12a. DISTRIBUTION/AVAILABILITY STATEMENT

Unclassified, Unlimited

12b. DISTRIBUTION CODE

A

13. ABSTRACT (Maximum 200 words)

The purpose of this study is to consider metrics with respect to the Air Force space launch program and recommend how they may contribute to the overall reliability assessment of space launch systems. This study will assess how a set of metrics can form the basis for reliability assessment of a typical space launch system.

14. SUBJECT TERMS

Reliability; Metrics; Spacecraft; Launch Systems; Air Force; Uncertainty; Vehicles; Tracking and Monitoring; Parameters; Measurements; Crews

15. NUMBER OF PAGES

25

16. PRICE CODE

17. SECURITY CLASSIFICATION OF REPORT	18. SECURITY CLASSIFICATION OF THIS PAGE	19. SECURITY CLASSIFICATION OF ABSTRACT	20. LIMITATION OF ABSTRACT
Unclassified	Unclassified	SAR	SAR

1.0 BACKGROUND

Reliability of launch systems is a current and historic concern in the space launch business. Program Managers, engineers and analysts have striven to increase launch reliability. As far back as 1960, General Power, Commander in Chief of the Air Force Strategic Air Command, warned that reliability improvements depended on an effective test program. Although engineers continuously sought product improvements to increase reliability, the Intercontinental Ballistic Missile Program suffered from failure after failure. Headquarters Air Force agreed with General Powers and encouraged more testing. However, they warned that the missiles were being "over exercised" suggesting the extensive testing may be negatively impacting reliability. The unreliability of the Atlas caused General LeMay, Air Force Chief of Staff, to form a board to investigate the causes of the continued failures. The board found many factors for the failures:

- inadequate testing,
- poor facilities,
- insufficient training,
- insufficient technical data,
- poor configuration control,
- poor quality control.[1]

In response to this study, the Air Force formed the Golden Ram Program. This program instituted all the findings. Prior to the study only 3 of 16 Atlas were successful. Afterwards 23 of 25 were successful. The Air Force has not applied this same type of rigorous study to the space launch fleet, although the same factors apply.

The Air Force faces a tough future in space launch systems. Launch rates are decreasing as budgets decrease and existing satellite systems out-live their planned lifetime. Additionally, Air Force satellites are not all common bus systems. In some cases, the systems are one of a kind. This makes the price of failure extremely high. Even in satellite systems that may have a manufacturing rate of two per year, a failure may mean six months or longer before a replacement is available. This down-time hurts the effectiveness of space systems in operational mission support and potentially compromises the ability of our space systems to support mission readiness in future years.

The purpose of this study is to consider these and other factors, or metrics, and recommend how they may contribute to the overall reliability assessment of space launch systems. This study assesses how a set of metrics can form the basis for reliability assessment of a typical space launch system.

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[1] Ballistic Missiles, Jacob Neufeld, Office of Air Force History, US Air Force, 1990, p 217.

2.0   RELIABILITY UNCERTAINTY

Analysts have developed complex and detailed methods for calculating the reliability of launch systems. However these methods have lacked the necessary data for a statistically significant calculation. The universal set is too small to derive any conclusions without significant caveats.

Without a significantly large data set, engineers have designed conservatism into their systems. Due to a lack of significant data, engineers "over design" to improve reliability. This is a contributing factor to high launch costs. Additionally, as new generation launch vehicles evolve from previous ones, the "over design" slowly erodes. Much of this erosion is justifiable since the data set is increasing. However, the universal set is still much too small for accurate assessments.

In recent years, the federal government encouraged contractors to develop launch systems using commercial practices. The rationale was for the manufacturers to become commercially competitive, reduce costs for government launches, and increase the number of launches. Although this has, in some cases, proven true (for example, Medium Launch Vehicle - III), there are significant cases where this approach has not helped to reduce costs or increase launch rate. Even in cases where the launch rate has increased, it has not increased in a statistically significant amount. The final results are launch systems no more reliable than previous ones. Additionally, by encouraging competitive practices, the Air Force owns less data and has a lesser ability to predict the success of future missions.

Because of the low use rate, space launch systems are a special case. From a reliability standpoint, factors that analysts and engineers normally dismiss as irrelevant require consideration. Since the high-level data set is not statistically significant, analyses must include the third, fourth, and fifth level factors. Every factor requires consideration unless substantial proof shows no effect on the overall launch system reliability. Unfortunately, the Air Force has never analyzed these lower level metrics and how they apply to space launches.

3.0   COMPONENTS OF LAUNCH RELIABILITY

Although the vehicular reliability of the launch system (Rv) is very important, the launch support reliability (Rs) is, in some cases, even more important. The actual reliability (Ra) of the complete launch system is a function of both Rv and Rs.

3.1   Vehicular Reliability (Rv)

Launch vehicle manufacturers advertise their Rv. This is a selling point for their systems. However, different contractors measure Rv in different ways. For example, Rv may be a quantity in their contract. Perhaps their current Rv is for a few vehicles (e.g., the last ten launches since incorporating certain product improvements). These values are purely right and proper, although one must realize what they reflect. Generally, reliability numbers listed in various payload users' manuals are a combination of system component reliabilities.

The contractors make vast assumptions in their reliability calculations that this paper contends are not true. For example, they assume the reliability of the launch crew is 1.0. Logically, they would portend that computer systems are sophisticated enough to scrub a launch if the launch crew makes an error in judgment. This is not so for the previous Titan IV failure at Vandenberg.[2] Although authorities did not hold the launch crew solely responsible for the failure, there were several decision points throughout the launch cycle where any engineer could have exercised judgment and stopped the processing. Should the launch crew have seen the failure and stopped the mission? No one knows for sure. The Office of Technology Assessment staff received a briefing at Vandenberg following a similar Titan 34D failure several years earlier. Vandenberg launch crews told them that even with additional testing instituted after the Titan 34D failure, engineers and operators at the launch site were not sure they could have prevented the failure. They had never faced that exact combination of factors. They may never face that combination again. This was proven true by the similar Titan IV failure. Although the failure mechanism was similar, the details were so different from the Titan 34D incident that the same did not apply. Because of this environment of uncertainty, there is no rational way an analyst can assume the reliability for the launch crew to be 1.0.[3][4]

Let's consider another example. The US Ranges are some of the best in the world. Once the current upgrade is complete, they will have the most reliable equipment; most experienced personnel; and most advanced architecture available. However, is their reliability 1.0? They would enjoy such a reputation. Even the most ardent Range fan will admit their systems have bad days. However, the reliability values in the Payload Users Manuals assume the Range reliability is 1.0.

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[2] The Titan IV failure was attributed to a solid rocket motor debonding. This was very similar to the Titan 34D failure in 1986. Although testing and screening for these debonds had been significantly increased since the 1986 failure, the ability to identify future failure was obviously not 100%.

[3] Reducing Launch Operations Costs, New Technologies and Practices, Congress of the United States, Office of Technology Assessment, September 1988

[4] For a detailed discussion of this Titan 34D failure and a comparison to the Challenger failure, see Guardians, Curt Pebbles, 1987.

Examples of this over simplification are numerous. All outside influences contribute to the reliability determination for a given launch vehicle system. Air Force Space Command has repeatedly stated that the real concern of the program manager or operator is: "What is the reliability of this system placing my satellite in the orbit where I need it?"[5] This reliability is not what is in the Payload Users Guides. To determine this reliability, we must consider Support Reliability (Rs).

3.2 Support Reliability (Rs)

The mission of the launch vehicle from the satellite program manager's point of view is to deliver a satellite to a defined orbit. Regardless of the sum of the piece part Rv values, regardless of the advertised reliability, this final placement of the satellite is the true purpose of the launch system. Much to the chagrin of the launch vehicle manufacturers, this berates the launch vehicle to nothing more than a transport. The launch vehicle is a single component in a complex system required to place the satellite in orbit.[6]

By considering the components of this complex system, we determine the factors of Rs.

1. **Facilities:** The facilities that support launch are critical. Although the computer system can shut down a launch in the final seconds if there is a facility problem, the impact of such a shutdown is significant and not entirely understood. The Titan 34D launch that crews scrubbed within seconds of liftoff due to a water valve not being replaced is a good example of the importance of facilities. In that case, the prevalves had opened on the Aerojet engines requiring a launch within 72 hours. Under time-critical conditions like this, reliability calculations become extremely difficult. Any accurate reliability figure must consider other factors besides Rv.

2. **Contractor Crew:** Much of the corporate memory is in the minds of the launch vehicle processing contractors. Although the contractors and the Air Force document decisions very carefully, nobody documents the engineering judgments that led to those decisions. As the contractor crews retire, shrink in size, or change jobs, the reliability does not go unaffected. An Rs value is necessary.

3. **Air Force Crew:** One of the main objectives of the Air Force Space Launch Squadrons is to provide mission assurance and safety oversight of the launch processing. Since very little of the processing is taught to the Air Force crews, and no automated database of histories (such as EMDAS and CAMS) exist. There is no educational process besides OJT that allows the Air Force crews to make top quality assessments of the contractor's work. They are, more often than not, in a "trust me" mode with the launch processing contractors. Because of this, one could argue that the Space

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[5] Various phone conversations with Headquarters Air Force Space Command Offices, April - May 1994.

[6] There have been some instances where the launch vehicle was as much a part of the mission as the payload it carried. Those experiments, however, are few.

Launch Squadron provides no value added. This is emphatically not the case. The Space Launch Squadron provides the satellite program manager and the operator with a presence that ensures contractors follow proper procedures. This becomes even more important as launch rates decrease and satellites are unique. The Air Force Crew is a critical part of the Rs equation when the entire system is taken into account.

4. **Range:** As mentioned earlier, the Range resources are critical to the success of any launch. These systems must be in top condition. Additionally, the Range crews must be trained on the launch profile and any peculiar details of the launch. Given the case of the Titan 34D scrub above, the Range capability to reorganize, reconfigure, and be ready to perform in a very limited time is essential. This process may warrants considerable attention since it is not routine.

5. **Weather:** This is a very uncertain parameter contributing to the probability of a launch success. As it applies to reliability, one needs to understand how accurately the weather is predicted. If there is a plane flying in the region reporting the weather conditions, the reliability of the reports may be higher than if the reports are written based on balloon data. The aircraft report reliability may increase if a weather expert is on the aircraft.

These are the primary factors of Rs. As Rs factors are tracked, recorded, and used, other factors may become apparent. This set is a good starting set. Together with Rv, we can determine the actual reliability of the system.

3.3   Actual Reliability (Ra)

The actual reliability of a launch system is what the satellite program manager wants to know. This value is a combination of the Rv and Rs. An understanding of this relationship is important. A linear relationship Ra = (Rv + Rs)/2 is an easy way to envision the use of Rv and Rs. The actual relationship between the two factors is beyond the scope of this study and would require further data gathering and manipulation.

The program manager can follow Ra throughout the development of the launch system until launch. Air Force Launch Crews could perform continuous assessment of Ra until the final launch commit decision. Although the Rv value is fairly rigid once the launch vehicle is at the launch site, it may change as components are removed and replaced. On the other hand, Rs may change drastically from day to day throughout the launch cycle. Given the proper ability to monitor and track Rs, the program manager can have the highest probability of success for any given launch.

4.0   TRACKING AND MONITORING Rs

To determine the data needed for each of the factors of Rs, a simple analysis of each factor is necessary. Each factor has several parts that effect launch. The parts effect launch availability, timeliness, responsiveness, or certainty. Other studies have identified these as critical items.[7] First consider definitions of these terms:

Launch Availability

This is a measure of the impact on the ability of the system to launch. For example, does a failure of this item cause the system not to launch? A practical example of this would be the launch pad crane. Certainly without it, there is no launch capability. Therefore a failure in the crane would cause concern and would impact the Rs of the system.

Launch Timeliness

This is a measure of the impact on the ability of the system to meet the required launch window. For example, does a failure of the item cause the system not to launch within the expected window? A practical example of this would be a range radar. If the radar goes down, it may take too long to repair causing a missed launch window.

Launch Responsiveness

This is a measure of the impact on the ability to respond to a launch on need or call-up requirement. For example, if a program has a launch on need requirement, does a failure of this item affect the system's ability to meet that requirement. If a program has a call-up requirement, the same criteria hold. A practical example of this would be a transporter. If a program had only one transporter and it failed, there would be doubts about the ability to meet a launch on need requirement.

Launch Certainty

This is a measure of the impact on the ability of the system to launch when expected. How certain is the program manager that the launch window will be met? For example, the weather plays a vital role in this factor. If the predicted weather is marginal, and the ability to predict it is not perfect, then this factor may be very large.

One can see how a given support item may fit into more than one of the criteria above. The key is that if it fits into any one, then it provides some kind of impact on Rs and needs to be monitored.

4.1   Parameters Within Each Factor

Each of the factors of Rs identified in Section 3.2 have parameters that need to be monitored. These parameters must fit the above criteria in some fashion. Initially, a

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[7] These items and others are described in detail in Military Space Forces, John M. Collins, 1989.

parameter may be considered critical. If, after several launches of monitoring it, the crews determine it has no impact on any of the criteria, it no longer necessitates monitoring. On the other hand, as certain parameters are monitored, crews may discover other parameters that become critical. These would be added for future launches. Based on the initial analysis, the following paragraphs outline the initial set of parameters necessary to develop an Rs value.

Facilities

There are three parameters within facilities that affect Rs. The number of supporting facilities is important. Obviously, the higher the number, the higher the probability of affecting the criteria. The amount of time since the last maintenance efforts in each facility must be monitored. The criticality of clean rooms is an important factor since there are many ways the lack of a clean room could impact the criteria.

FACILITIES PARAMETERS
Number of supporting facilities
Time since last maintenance efforts
Criticality of Clean Rooms

Contractor Crew

The contractor crew have several items which impact their reliability. The number of new people and the number of losses since the last launch is critical. Amount of training performed by each crew member in specific skills is important. Other contributing factors include the length of the shifts and the length of the launch cycle.

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CONTRACTOR CREW PARAMETERS
Number of new personnel since last launch
Number of losses since last launch
Training in specific skills areas
Length of shifts worked
Length of launch cycle
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Air Force Crew

The Air Force Crew is similar to the contractor crew. They have basically the same parameters for monitoring. However, the criteria are weighed differently. This is predominantly driven by the frequency of turnover in Air Force personnel. Where contractor crews tend to stay with the launch team for a significantly long time (20 years), the Air Force crew is short lived (3-5 years). This is reflected in their duties; Air Force crews provide oversight whereas the contractor crews perform the actual work. Additionally, because of the high turnover rate, training is very important.

```
AIR FORCE CREW PARAMETERS
Number of new personnel since last launch
Number of losses since last launch
Training in specific skills areas
Length of shifts worked
Length of launch cycle
```

Range

The value and potential impact of the Range is too extensive to encapsulate in just a few short lines. Each program needs to assess which items are significant and to what degree. A start would be to monitor all the mandatory items listed in the Program Requirements Document. In addition to these items, there are other concerns a program may want to track. These would include similar crew concerns as the contractor and Air Force items

listed above. Length of time since the last maintenance performed and redundancy on critical equipment is important.

RANGE PARAMETERS
Number of new personnel since last launch
Number of losses since last launch
Amount of training on mission
Length of shifts worked
Amount of mandatory resources required
Time since last maintenance on madatory items
Amount of redundancy in mandatory items

Weather

Although some may consider this a part of the Range resources, it has been significantly critical in the past to warrant separate consideration. Data has shown that Weather has been responsible for as much as 11% of the launch delays recorded. This number may be higher except that some delays were shadowed by additional problems with Range or the launch system.[8] Weather parameters must be well defined. They include the number of radar used, the number of aircraft used, the susceptibility of the system to weather, the confidence of the forecast, and the amount of training the weather personnel have received on the program. For example, if weather balloons are used for measurements of winds aloft, then the reliability of that forecast would be less than if radar and aircraft are used to provide measurements. Additionally, the older the forecast, the lesser the reliability.

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[8] NSIA Launch Responsiveness Launch System Panel Results, June 1994

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WEATHER PARAMETERS
Time since last forecast
Sophistication of measurement equipment
Training of Weather Crews
Susceptability of mission to weather
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4.2   Application of the Parameters

Each program evaluates parameters differently, so any example we consider is hypothetical. For this study, assume a program launches from only one launch site.

Each launch system has a Readiness Review Cycle it passes through as the system is prepared for launch. Each of the Readiness Reviews are linked to a milestone event in the launch preparation activities. At each one of these Readiness Reviews, an Rs value should be evaluated and assessed. As the launch approaches, there should be a continual, perhaps hourly, updating of Rs until the final commit to launch.

A typical launch cycle may have the following reviews: [9]

Postproduction Review

This review is conducted at the contractor's manufacturing facility at the end of production. The primary purpose of this review is to assure the hardware is ready for shipment to the launch site.

Pre-Vehicle-On-Stand Review

This review is held after the preliminary receipt and checkout of the launch system is complete. The primary purpose of the review is to assure the system is ready to be placed on the launch pad.

Launch Site Readiness Review

This review is held prior to the erection and mate of the upper stage and satellite. The primary purpose of the review is to assess progress since the Pre-Vehicle-On-

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[9] This list of reviews reflects those described in the Commercial Delta II Payload Planners Guide, McDonnell Douglas Commercial Delta, Inc., December 1989.

Stand Review. This review verifies readiness of all system components for transfer of the satellite to the launch pad.

Flight Readiness Review

This review is held upon completion of combined system testing. It verifies the satellite and launch system are ready for countdown and launch. The purpose of this review is to get corporate approval from all the various agencies supporting the launch that they are ready to proceed into final launch preparations.

Launch Readiness Review

This review is held the day prior to beginning the final launch countdown. This forum provides all agencies an opportunity to discuss any concerns regarding launch. It also assures all agencies are prepared to proceed. The purpose of this review is to get approval to start the terminal countdown.

Various factors of Rs carry different importance at different reviews. For example, Weather parameters do not have much bearing on the readiness for the system to be sent to the launch site. However, the readiness is affected by contractor crew training. The following chart is a sample of how the parameters could be tracked for each review.

	POSTPRODUCTION REVIEW	PRE-VEHICLE-ON STAND REVIEW	LAUNCH SITE READINESS REVIEW	FLIGHT READINESS REVIEW	LAUNCH READINESS REVIEW
FACILITIES					
NUMBER OF SUPPORTING FACILITIES					
TIME SINCE LAST MAINTENANCE EFFORTS					
CRITICALITY OF CLEAN ROOMS					
CONTRACTOR CREWS					
NEW PERSONNEL SINCE LAST LAUNCH					
NUMBER OF LOSSES SINCE LAST LAUNCH					
TRAINING IN SPECIFIC SKILL AREAS					
LENGTH OF SHIFTS WORKED					
LENGTH OF LAUNCH CYCLE					
AIR FORCE CREW					
NEW PERSONNEL SINCE LAST LAUNCH					
NUMBER OF LOSSES SINCE LAST LAUNCH					
TRAINING IN SPECIFIC SKILL AREAS					
LENGTH OF SHIFTS WORKED					
LENGTH OF LAUNCH CYCLE					
RANGE					
NEW PERSONNEL SINCE LAST LAUNCH					
LOSSES SINCE LAST LAUNCH					
AMOUNT OF TRAINING ON MISSION					
LENGTH OF SHIFTS WORKED					
AMOUNT OF MANDATORY RESOURCES REQUIRED					
TIME SINCE LAST MAINTENANCE ON MANDATORY ITEMS					
AMOUNT OF REDUNDANCY IN MANDATORY ITEMS					
WEATHER					
TIME SINCE LAST FORECAST					
SOPHISTICATION IN MEASUREMENT EQUIPMENT					
TRAINING OF WEATHER CREWS					
SUSCEPTIBILITY OF MISSION TO WEATHER					

This type of matrix would provide the mission director the ability to monitor the progress of each Reliability area. Each area could be tracked throughout the launch processing sequence. This would identify risks in areas that are not currently monitored in this manner. It is important to note these items are currently being tracked in some fashion. For example, the readiness of the Range is constantly tracked and assessed. The uniqueness of this approach is that it assesses the readiness of the Range to support one

particular mission. Although the Range tracks and evaluates the readiness of each mandatory item, the reliability of a system is directly related to how many mandatory items are necessary for that system to launch.

This same approach would hold true for Weather. Although Weather crews have specific guidelines that tell them what weather situations are most important for a given mission, how susceptible that mission is to those weather situations is an evaluation only performed by the Mission Director. Obviously, it will rely on how well the Weather Crews are trained to respond to the peculiarities of the mission.

This approach puts the responsibility of the success of the mission where it should be-- with the Mission Director. It allows the crews a method of identifying areas where they perceive problems exist. If they do not have enough training to perform the mission, then the training is rated low. If they do not have the personnel they need or if they are working longer periods than what is healthy, then those ratings are low.

4.3   EVALUATION TECHNIQUES

Using the parameters in the hypothetical program, each needs to be assessed against the criteria of launch availability, timeliness, responsiveness, and certainty. This should be an effort performed by the Space Launch Squadrons. This assessment would provide a scale for the detailed reliability analysis. The scale shown here, as with the parameters, is only a hypothetical approach. Note that the effect of some of the parameters on some of the criteria can not change without a significant redesign of the program. Others can change simply with quality planning. We will show later how the evaluation will change throughout the launch process.

4.3.1   FACILITIES EXAMPLE

Number of Supporting Facilities

Rating	Description
0	Has no facility requirements.
1	Only requires single facility or has no special facility requirements.
2	Requires a few facilities, but has flexibility in where those facilities exist.
3	Requires several facilities. Has specific requirements that are unique, but manageable with other programs.
4	Requires several facilities that are well defined. Requires modification of existing facilities to perform successful mission
5	Requires several facilities to function in coordination with each other. Each facility is uniquely tailored to the specific mission. No flexibility if a facility is not available.

Time Since Last Maintenance Efforts

Rating Description
- 0 No maintenance scheduled throughout the launch cycle.
- 1 All maintenance items complete within the previous three months.
- 2 All maintenance items complete within the previous six months.
- 3 All maintenance items complete within the previous year. 80% within the previous six months.
- 4 All maintenance items complete within the previous year. 50% within the previous six months.
- 5 Some maintenance performed over a year ago.

Criticality of Clean Rooms

Rating Description
- 0 No clean room required for mission success.
- 1 Mission only requires special handling for environmental protection
- 2 Mission only requires an environmental protection room.
- 3 Mission requires a visibly clean work environment.
- 4 Mission requires a specific level clean room for part of the processing period.
- 5 Mission requires a specific level clean room continuously throughout the launch processing.

4.3.2 EVALUATION THROUGH THE LAUNCH PROCESS

Now consider how the above criteria might be evaluated through a typical launch cycle. The following figure shows a sample evaluation prior to the postproduction review.

SAMPLE MISSION	POST PRODUCTION REVIEW	PRE-VEHICLE-ON-STAND REVIEW	LAUNCH SITE READINESS REVIEW	FLIGHT READINESS REVIEW	LAUNCH READINESS REVIEW
FACILITIES					
NUMBER OF SUPPORTING FACILITIES	4				
TIME SINCE LAST MAINTENANCE EFFORTS	4				
CRITICALITY OF CLEAN ROOMS	3				

This sample shows that the program has several facilities that are well defined, but require modifications. All maintenance has been completed within the last year. The mission requires only a visibly clean work environment to get to the next milestone. The facilities support reliability could be calculated using the following formula:

$$Rs(facilities) = 1 - \left[\left(\frac{4+4+3}{5}\right)/3\right] = .27$$

A more thorough analysis will be necessary to determine the exact relationship of each of these parameters. Certain programs may want each parameter weighed differently or calculated in a combination of parallel and serial relationships (see Section 4.4). However, for this example a simple corrected mean calculation is sufficient to show the methodology. For a highly reliable system, the number approaches "1". The method reveals areas of vulnerability allowing directors to correct situations as they approach launch. Additionally, this approach will identify continuous problem areas associated with all launches.

As the program enters the next phase they hold the Pre-Vehicle-on-Stand Review. During this review the reliability is once again considered. As before, the example here only considers facilities. However, in practice all areas will be reconsidered prior to each milestone review.

SAMPLE MISSION	POST PRODUCTION REVIEW	PRE-VEHICLE-ON-STAND REVIEW	LAUNCH SITE READINESS REVIEW	FLIGHT READINESS REVIEW	LAUNCH READINESS REVIEW
FACILITIES					
NUMBER OF SUPPORTING FACILITIES	4	3			
TIME SINCE LAST MAINTENANCE EFFORTS	4	3			
CRITICALITY OF CLEAN ROOMS	3	1			

In this example, we see changes at this milestone. Although the program requires several facilities, they are more well-defined for this stage. No modifications are necessary. The maintenance crews have caught up on more of the maintenance items, although this is still a problem area. Only environmental covers on sensitive surfaces are necessary for the next phase, so this area is rated at "1". This yields a Facilities Support Reliability of:

$$Rs(facilities) = 1 - \left[\left(\frac{3+3+1}{5}\right)/3\right] = .53$$

This shows that the reliability related to the facility support has doubled since the last review. This shows a good trend as we approach launch. The next milestone, the Launch Site Readiness Review, is usually done prior to bringing the satellite out to the launch pad. Launch controllers are usually very particular about making sure the chances of a launch in the near future are very high. Therefore, the support reliability number at that stage is very important. Since most satellites require some sort of clean room environment on the launch pad, the Criticality of the Clean Room becomes significant. Things to considered are:

How quickly can the satellite be "safed" if the power is lost to the clean room?
How sensitive is the satellite to fluctuations caused by the extreme temperatures?
What is the impact if we lose the clean room facility completely? Do we not launch?

These questions become very critical at this stage. The answers could vary significantly. In our example, we assume the satellite requires a minimum clean room facility only during certain times in the prelaunch activities. By this time all the old maintenance items are complete, and the number of facilities supporting the activities has dropped significantly. This gives the following chart:

SAMPLE MISSION	POST PRODUCTION REVIEW	PRE-VEHICLE-ON-STAND REVIEW	LAUNCH SITE READINESS REVIEW	FLIGHT READINESS REVIEW	LAUNCH READINESS REVIEW
FACILITIES					
NUMBER OF SUPPORTING FACILITIES	4	3	2		
TIME SINCE LAST MAINTENANCE EFFORTS	4	3	2		
CRITICALITY OF CLEAN ROOMS	3	1	4		

Based on this information we can see that the facility support reliability changed again.

$$Rs(facilities) = 1 - \left[\left(\frac{2+2+4}{5} \right) / 3 \right] = .47$$

As we approach the Flight Readiness Review, the clean room facility is no longer important since the payload fairing is in place. This milestone is usually to assess the readiness of the system to load propellant on the booster. The process still requires protection from the elements. By this time all maintenance items should be completed.

SAMPLE MISSION	POST PRODUCTION REVIEW	PRE-VEHICLE-ON-STAND REVIEW	LAUNCH SITE READINESS REVIEW	FLIGHT READINESS REVIEW	LAUNCH READINESS REVIEW
FACILITIES					
NUMBER OF SUPPORTING FACILITIES	4	3	2	2	
TIME SINCE LAST MAINTENANCE EFFORTS	4	3	2	1	
CRITICALITY OF CLEAN ROOMS	3	1	4	2	

By this time we are approaching a critical point in the reliability calculation. Any extensive effort to improve the reliability numbers from this point on will likely cause a launch delay. The calculated Facility Support Reliability at the Flight Readiness Review is:

$$Rs(facilities) = 1 - \left[\left(\frac{2+1+2}{5} \right) / 3 \right] = .67$$

At the Launch Readiness Review, the number of facilities supporting the operation goes up significantly, however, they are well defined. Because of the large volume, the number still remains high. No clean room is necessary for any further operation, and all maintenance items are complete.

SAMPLE MISSION	POST PRODUCTION REVIEW	PRE-VEHICLE-ON-STAND REVIEW	LAUNCH SITE READINESS REVIEW	FLIGHT READINESS REVIEW	LAUNCH READINESS REVIEW
FACILITIES					
NUMBER OF SUPPORTING FACILITIES	4	3	2	2	3
TIME SINCE LAST MAINTENANCE EFFORTS	4	3	2	1	1
CRITICALITY OF CLEAN ROOMS	3	1	4	2	0

This is the last milestone assessment prior to launch. The number should not change between this milestone and launch. The changes are not in the measures of merit, but in the operations of those measures. For example, the number of buildings will not change. However, a particular facility may lose power and impact the operation. This will not have an effect on the numbers as we have calculated them. That evaluation will be an integral part of the countdown process. The calculated Facility Support Reliability presented at the Launch Readiness Review is:

$$Rs(facilities) = 1 - \left[\left(\frac{3+1+0}{5} \right) / 3 \right] = .73$$

This process shows that a program director, launch controller, and all other parties can follow the support reliability throughout the entire launch processing flow. It shows how the reliability can change and how it reacts to outside circumstances. This sample is a fairly common approach. However, each program is different. Given the proper software tools a comparison to the previous mission could be done showing the significant differences only.

4..3.3 INTEGRATED EXAMPLE

This same process would apply to the other parameters throughout the process. An integrated example may look like the following matrix:

	POSTPRODUCTION REVIEW	PRE-VEHICLE-ON STAND REVIEW	LAUNCH SITE READINESS REVIEW	FLIGHT READINESS REVIEW	LAUNCH READINESS REVIEW
FACILITIES					
NUMBER OF SUPPORTING FACILITIES	4	3	2	2	3
TIME SINCE LAST MAINTENANCE EFFORTS	4	3	2	1	1
CRITICALITY OF CLEAN ROOMS	3	1	4	2	0
CONTRACTOR CREWS					
NEW PERSONNEL SINCE LAST LAUNCH	4	3	3	2	2
NUMBER OF LOSSES SINCE LAST LAUNCH	5	5	4	4	4
TRAINING IN SPECIFIC SKILL AREAS	2	2	1	1	1
LENGTH OF SHIFTS WORKED	0	2	4	2	1
LENGTH OF LAUNCH CYCLE	0	0	1	1	1
AIR FORCE CREW					
NEW PERSONNEL SINCE LAST LAUNCH	5	5	4	4	3
NUMBER OF LOSSES SINCE LAST LAUNCH	5	5	4	3	3
TRAINING IN SPECIFIC SKILL AREAS	4	4	3	3	3
LENGTH OF SHIFTS WORKED	0	2	4	2	1
LENGTH OF LAUNCH CYCLE	0	0	1	1	1
RANGE					
NEW PERSONNEL SINCE LAST LAUNCH	3	4	4	3	3
LOSSES SINCE LAST LAUNCH	4	4	4	3	3
AMOUNT OF TRAINING ON MISSION	5	5	2	1	1
LENGTH OF SHIFTS WORKED	0	1	3	4	5
AMOUNT OF MANDATORY RESOURCES REQUIRED	0	1	4	5	5
TIME SINCE LAST MAINTENANCE ON MANDATORY ITEMS	5	4	2	2	2
AMOUNT OF REDUNDANCY IN MANDATORY ITEMS	0	1	2	2	2
WEATHER					
TIME SINCE LAST FORECAST	0	1	2	2	2
SOPHISTICATION IN MEASUREMENT EQUIPMENT	4	4	4	4	4
TRAINING OF WEATHER CREWS	5	4	2	2	2
SUSCEPTIBILITY OF MISSION TO WEATHER	0	3	5	4	3

Assuming the relationships described earlier, the Rs(sum) would be the following for each review milestone.

Rs Value Summary	POSTPRODUCTION REVIEW	PRE-VEHICLE-ON-STAND REVIEW	LAUNCH SITE READINESS REVIEW	FLIGHT READINESS REVIEW	LAUNCH READINESS REVIEW
FACILITIES	0.27	0.53	0.47	0.67	0.73
CONTRACTOR CREWS	0.56	0.52	0.48	0.60	0.64
AIR FORCE CREWS	0.44	0.36	0.36	0.36	0.56
RANGE	0.51	0.43	0.40	0.43	0.40
WEATHER	0.55	0.40	0.35	0.40	0.45
OVERALL	0.47	0.45	0.41	0.49	0.56

From this example, we can clearly see how the Rs value fluctuates throughout the launch processing cycle. Although a more thorough examination of the various related factors would show additional parameters to monitor, this example shows a fair representation of Rs.

4.4 TRUE RELIABILITY CALCULATIONS

The example in Section 4.3 is a hypothetical example. The best practice is to have several metrics monitored on a periodic basis. Section 4.3 shows a method for manual calculation of the Rs value. Ideally, it would be calculated using computers monitoring specific functions. For example, all the crew data would be in a database. The Rs calculation for the crew would draw its references from the database.

Additionally, a history of events is necessary to perform a quality Rs calculation. Until that history is available, a simpler calculation is appropriate. However, once a data set of significant size is developed, then the reliability calculations should become more rigorous and more typical.

The reliability function is typically determined from the probability of system success. The reliability function, R(t), is defined as

$$R(t) = 1 - F(t)$$

with F(t) as the probability of failure during time t. F(t) is the failure distribution function. If the variable t is described by f(t), then the expression for reliability is

$$R(t) = 1 - F(t) = \int_t^\infty f(t)dt$$

describing the time to failure with a exponential density function gives

$$f(t) = \frac{1}{\theta}e^{-t/\theta}$$

where θ is the mean life and t the period of interest. So, the reliability at time t is

$$R(t) = \int_t^\infty \frac{1}{\theta}e^{-t/\theta}dt = e^{-t/\theta}$$

Mean life (θ) is the arithmetic average of the lifetimes of all items considered which for the exponential function is Mean Time Between Failure (MTBF). So,

$$R(t) = e^{-t/M} = e^{-\lambda t}$$

where λ is the instantaneous failure rate and M the MTBF.

This approach identifies a typical calculation for determining a reliability value for a given period of time. Therefore, the same approach applies to the matrix in Section 4.3 for space launch systems. Obviously, for this calculation to be useful, there needs to be a sophisticated database of historical values. Determining the Mean Time Between Failures for each of the support parameters is a significant effort. However, it is necessary to accurately assess the Rs.

A launch system is a combination of series and parallel networks. Traditional definitions of these are:

Series Networks

In a series network all components must operate in a satisfactory manner for the system to function. If the system includes subsystem A, subsystem B and subsystem C, the reliability of the system is the product of the reliabilities of the individual subsystems

$$reliability(R) = (R_A)(R_B)(R_C)$$

Parallel Networks

A parallel network is one where a number of the same components are in parallel and where all the components must fail in order to cause total system failure. For a system with subsystems A and B the reliability is expressed as:

$$reliability(R) = (R_A + R_B) - (R_A)(R_B)$$

Further studies could determine how the various parameters within each support factor defined in Section 4.1 relate to each other. Some are parallel and some are serial.

5.0   CONCLUSIONS

The space launch industry needs a more complete reliability monitoring system. This is essential as the launch rates decrease. Air Force launch crews can take simple to assist in building a true reliability capability.

The universal data set for space launch systems is statistically insignificant to warrant exclusion of factors others may consider third or fourth order. These factors include calculations of the reliability of more than simply the launch vehicle hardware. Based on studies previously performed by the Air Force, this data set should include:

- ➲ Facilities
- ➲ Contractor Crew
- ➲ Air Force Crew
- ➲ Range
- ➲ Weather

There may be other factors, but these are critical for beginning to develop a support reliability system. These factors have specific parameters, or metrics, that are tracked against a scale. These scaled values allow program managers to make a complete reliability assessment throughout the launch processing cycle. This Actual Reliability (Ra) is a function of both the launch vehicle Reliability (Rv) and the support system Reliability (Rs). The exact relationship needs to be determined for each launch system.

Ra should be monitored throughout the launch processing cycle. It should be a vital part of the decision making process for launch. After a few launches, program managers can compare the current launch to previous launches. This adds confidence in the ability of the entire system.

6.0   RECOMMENDATIONS

1. The Air Force should implement a reliability monitoring and tracking system. This system should track key parameters within the factors described in Section 4.1.

2. Further studies should be done to determine the actual relationships between the various parameters. This study should define where the serial and parallel relationships exist. It should also identify the proper weighting of the various parameters. For example, if the facilities are twice as important as the contractor crew, then it would be weighted by a factor of 2. This would define the proper weighting of the various parameters.

3. One launch system should be identified for a test case for implementing this reliability approach. This could be done on a non-interference basis. As the launch processing was completed, the various reliability factors could be tallied. This would give the Air Force an indication of success of this approach.

APPENDIX A

ACRONYMS

CAMS .... Core Automated Maintenance System
EMDAS .... Enhanced Missile Data Acquisition System
MTBF .... Mean Time Between Failures
OJT .... On the Job Training
Ra .... Actual Reliability
Rs .... Support Reliability
Rv .... Vehicle Reliability

APPENDIX B

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